Potential, Current & Resistance

Experiment EX11

Part A: ***Practicing with PhET (home assignment)***
Part B: ***Investigating and measuring Circuits***

Time Required for Completion: Approximately 100 minutes.
Lab Report Grading Guide: Introduction (*10 pts*), Data (*20 pts*), Data Analysis [Narrative (*30 pts*) & Analysis Questions (*30 pts*)], Conclusion (*10 pts*).

OBJECTIVE

- To investigate the conceptual relationship of potential, current, and resistance
- To become familiar with the physical measurement of potential, current, and resistance

EQUIPMENT NEEDED

Experiment Apparatus:
Evans Circuit Modeling Kit™ (CMK-1)
Simple Digital Voltmeter

SPECIAL INSTRUCTIONS

This experiment is a bit involved and may take nearly the entire lab period to complete! Consequently, the customary experiment introduction by the lab instructor may be somewhat curtailed. You must read the theory section prior to coming to lab! ***You should also familiarize yourself with the theory of circuits and practice beforehand by doing the PhET simulations (Part A) on your own before the lab (see below).***

THEORY

The interaction of components in an electric circuit is based upon the relationship of potential, current, and resistance.

Voltage (*V*) or **"electric potential"** is the *amount of electrical potential energy provided to or taken away from each charge*. The voltage "pushes" the current through the circuit, much like a pump "pushes" water through water pipes. Voltage is measured as the difference between two points. The unit of measurement for voltage is the **volt** (*V*).

The voltage is provided by a **Voltage Source** such as a battery or generator. These typically provide as much current as desired at a constant voltage leg: 1.5 V for a (AAA, AA, C or D) cell battery or 120 V for an electrical wall outlet.

Current (*I*) describes the *amount of electrical charge flowing through a circuit*. The total current in a circuit is typically the current flowing through the battery or other voltage source. The unit of measurement for current is the **ampere** (*A*).

Resistance (*R*) is a physical characteristic of objects in the circuit that *impede the flow of charges through a circuit*. Not surprisingly, objects made of different materials may have different resistances and all materials have some degree of resistivity, making them either well or ill-suited for use in electrical circuits. Materials that have low resistivity are called **Conductors**, while materials that have high resistivity are called **Insulators**. The unit of measurement for resistance is the **Ohm** (Ω).

For any object of resistance *R* within a circuit, the current flowing through that object and the voltage drop across it are related by $\Delta V = R \cdot I$ (Ohm's Law). Here the voltage decreases along the current flow. If the object is a light bulb, it will emit light if enough current flows – the brightness of the light is proportional to the **square** of the current. Because of Ohm's law, it is also proportional to the (squared) voltage drop across the light bulb. Therefore, the intensity of the light can be used as a rough indicator of both the current through (and the voltage drop across) a light bulb.

Schematic Diagrams

Electrical circuits are designed using standardized **Schematic Symbols** which represent the components used in the circuit. Figure EX11.1 shows some common schematic symbols.

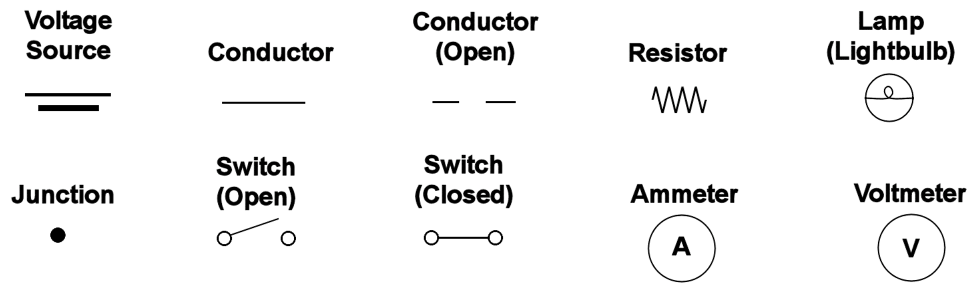


Figure EX11.1: Common Schematic Symbols

On a **Schematic Diagram**, these symbols tell at a glance exactly what components are used in the circuit, and more important, they enable the viewer to *trace the flow of electrical current throughout the circuit*. <u>In short, schematic diagrams provide a graphical description of what components are to be used and how the circuit is intended to function</u>.

Tracing Current Flow in a Schematic Diagram

Regardless of whether (AC) or (DC) is used in the circuit, the rules for tracing current flow in schematic diagrams are very simple:

- Current flow through the circuit components is **from the positive terminal of the power source to the negative terminal of the power source.**
- There **must be a complete path** (no breaks), from the negative terminal to the positive terminal, **or current will not flow along that path**.
- Depending on the configuration of the circuit, **there may be multiple, concurrent paths allowing current flow**.
- Any **two points connected by a conductor (wire) in an electrical circuit are electrically equivalent**. In a schematic, all components connected to any one solid line or joined at a **Junction Point** to the solid line; provide an electrical path for current flow in the circuit.

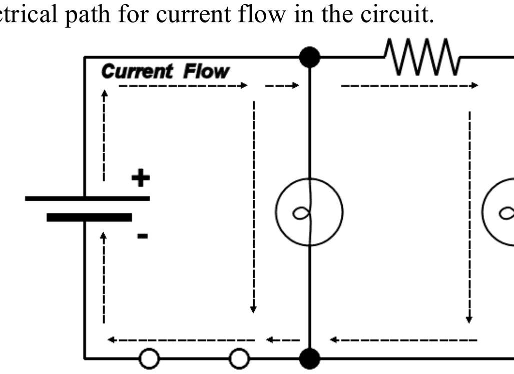


Figure EX11.2: Sample Schematic Diagram Showing Traditional Current Flow

Batteries

Batteries are *self-contained voltage sources* that produce electrical potential through chemical, rather than mechanical means, and they have a defined voltage storage capacity. The common household (**1.5 volt, "AA" cell**) batteries used in this experiment, like all batteries, have a positive and negative terminal. The *positive terminal* is the **protruding pole on the top of the battery** and the *negative terminal* is the **entire bottom of the battery**.
The voltage in a circuit may be increased by connecting individual batteries together in series. To connect batteries in series, connect the positive terminal of one battery to the negative terminal of another battery. The remaining free "+" and "–" terminals of the combined batteries can then be connected to your circuit. This has already been accomplished in this experiment through the use of a double battery holder.

Resistors

Resistors impede the flow of current through a circuit and have a fixed resistance and power handling value. **Light bulbs** are treated in circuits as plain resistors in that they also have a fixed resistance (not quite true in real life). The more current flowing through a light bulb, the brighter it will glow (see first page).

Wires on the other hand, have very little resistance. They are treated in circuits as having zero resistance. However, a broken wire or an open switch will not let current flow through a circuit. In effect, they have infinite resistance.

Resistance in Series, Parallel, and Combination Configurations

In order to ensure the proper functioning of electronic circuits, circuit resistance is carefully determined during the design phase. Depending on the component, the value of the resistance may be either fixed or variable. Resistance may be configured in three ways: series, parallel, or a combination of series & parallel.

Resistance in Series Circuit Configurations

When connected such that ***all*** of the current has a **single pathway** to flow through each circuit component (essentially connected, end to end), as shown in Figure EX11.3, then the components are said to be connected in ***series***.

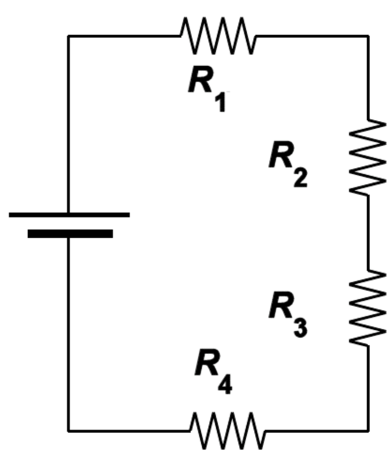


Figure EX11.3: Series Configuration

In order to apply Ohm's Law to a circuit in which the resistors are combined in a series configuration, you must use a formula to determine the **total value of resistance**—in effect, the **equivalent value** of a single resistor $R_{equiv\,s}$, which could replace the other resistors in a series configuration.
For resistance in series configuration the formula is:

$$R_{equiv\ s} = R_1 + R_2 + R_3 + \dots R_N \qquad (3)$$

Resistance in Parallel Circuit Configurations

When circuit components are connected such that the current has more than one **parallel pathway** through which it can flow, as shown in Figure E11.4, then the components are said to be connected in ***parallel***.

Note: Each **individual pathway** in a parallel circuit is commonly referred to as a "**leg**". Commonly, the legs in a circuit are sequentially numbered from left to right for easy reference.

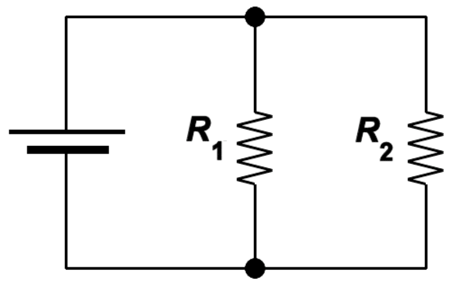


Figure EX11.4: Parallel Configuration

In order to apply Ohm's Law to a circuit in which the resistors are in a parallel configuration, you must use a formula to determine the total value of resistance—in effect, the **equivalent value** of a single resistor $R_{equiv\ p}$, which could replace the other resistors in a parallel configuration.

For resistance in parallel configuration the formula is:

$$\frac{1}{R_{equiv\ p}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \frac{1}{R_N} \qquad (4)$$

Note: To find the $R_{equiv\ p}$ value you will use in circuit resistance calculations, take the **inverse**: $\left(\frac{1}{R_{equiv\ p}}\right)^{-1}$.

Resistance in Combination Circuit Configurations

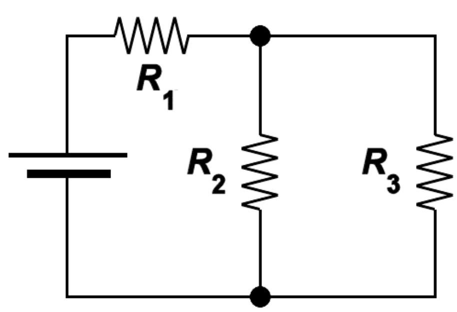


Figure EX11.5: Combination Configuration

In order to apply Ohm's Law to determine the equivalent resistance of a circuit containing resistors which are in a combination of series and parallel, you must do a deeper analysis:

- Determine which resistors are in parallel with each other. As shown in Figure EX11.5, R_2 and R_3 are in parallel.

- Using Equation (4), replace R_2 and R_3 with a single equivalent resistance $R_{equiv\ p}$, which as shown in Figure EX11.6, effectively reduces the combination circuit to a series circuit.

$$R_{equiv\ p} = R_{23} = \frac{1}{\frac{1}{R_2} + \frac{1}{R_3}}$$

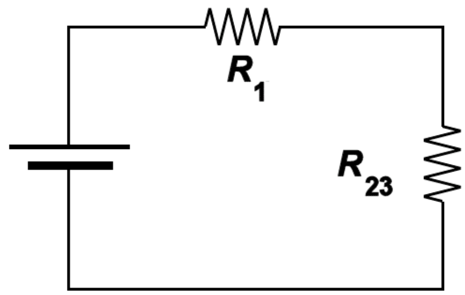


Figure EX11.6: Combination Circuit Reduced to a Series Circuit

- Lastly, determine which resistors are in series with each other, in this case it is R_1 and R_{23}, and use Equation (3) to solve for $R_{equiv\ s}$ in the circuit. If we assume that the voltage source has negligible resistance (as we do in this experiment), the result is equal to the **total resistance** R_{Total} of the circuit.

PROCEDURE

Part A (at home): Practicing with PhET

The University of Colorado's Physics Education Technology (PhET) project has created a computer-based program of "virtual" physics simulations designed to assist students in understanding the basic principles behind a variety of physics concepts.

As part of your "at home" preparation **BEFORE** this lab, you will use the PhET "Circuit Construction Kit" (CCK) to measure values in "virtual" electronic circuits identical to those you will explored in Part B of experiment E11 in the lab. (While this part is strictly speaking voluntary, you will have a much easier time with the real experiment if you do it beforehand!)

Note: In many textbooks the "Traditional" method of explaining current flow (***positive to negative***) is used when teaching the basics of electronics. This method developed because before the discovery of the electron, nobody knew whether the moving charge carriers in a circuit are positively or negatively charged. However in reality, it is actually the *negatively charged* **electrons** that move through the circuit.
The PhET CCK simulations **do not** use the "Traditional" method of describing current flow. Instead, it shows the current flowing from the ***negative terminal of the voltage source to the positive terminal of the voltage source***. Therefore, you should use (***negative to positive***) as the basis when making current flow predictions in Part I.

● Computer Setup

1. Find a computer you can use – your own, in an ODU computer lab, or the Physics Learning Center. In the following, it is assumed that you have a web browser running on the computer and that Java is installed on it.

2. Go to http://phet.colorado.edu/index.php

3. Click on the reddish button "Play with sims…>".

4. From the next screen, select the **Circuit Construction Kit (DC Only)** by clicking on the picture of the kit.

5. Either download the application and start it up, or click on "Run Now". The following three items 6-8 are optional.

6. On the top menu of the CCK main screen, click on **Options** to open a drop-down menu. Click the **Background Color** choice on the drop-down menu. A color palette window will open.

7. Click on the **RGB** tab. Change the values in the **RGB** windows to: **Red=0, Green=102, Blue=0**, and click the **OK** button to accept the values and close the window. Your CCK work area should now have a green background that will produce a high contrast to the CCK components.

8. Use the mouse to <u>drag and drop a section of wire onto the work area</u>. Move your mouse over the wire and <u>right click</u> the mouse. Select the "**remove**" option and <u>left click</u> to accept the choice. This will clear the distraction of the animated "**Grab a Wire**" message from the work area. The customized PhET CCK screen should now appear similar to that shown in Figure EX11.10.

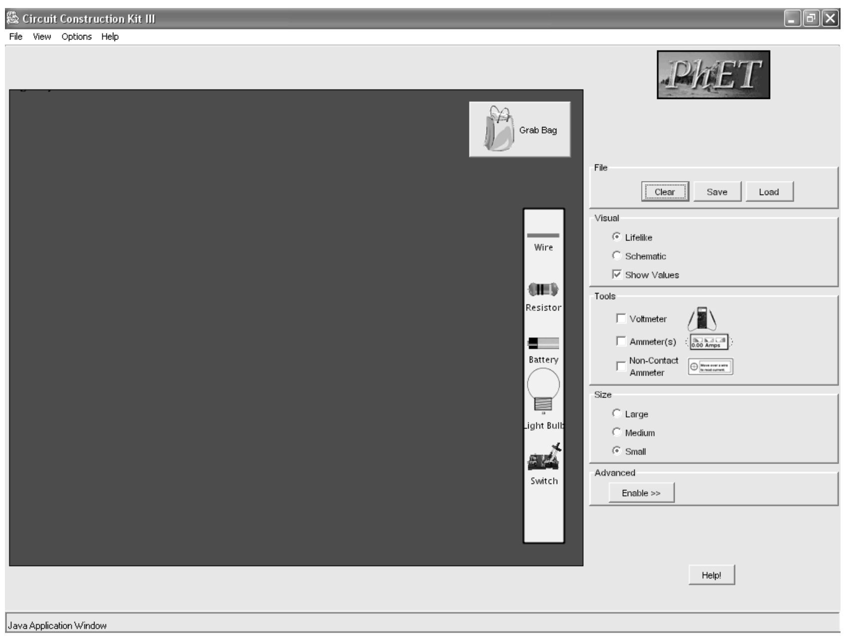


Figure EX11.10: Customized PhET CCK Main Screen

● Measuring Values—Series Circuits

1. Using drag and drop, "build" circuits CKT01 through CKT03 (one after another or simultaneously) from the available parts (wires, battery and light bulbs). Note: You can drag the ends of wires to make them shorter, longer, or orient them differently.

2. For the following, fill out Data Tables 4-6 (but you won't be graded on them).

3. Observe and record the current flow path(s) in each circuit directly on the Data Table 4 schematic.

4. Examine the length of the rays emanating from the lamps and in order of brightness from brightest (1) to dimmest (3), or equal, record the rank of the circuits directly on the Data Table 4 schematic.

5. On the CCK right-hand menu under the **Tools** section, click the **Non-contact Ammeter** box. A white box

with a crosshair will open. Move the crosshair over the circuit wiring corresponding to the **Test Points** TP **numbers** (refer to the Data Table 4 schematic), designated in the ***current measurements section*** of Data Table 4. Record in the ***current measurements section*** of Data Table 4, the value of the **current** at each designated test point. When you have completed the data collection, uncheck the box to turn off the tool.

6. On the CCK right-hand menu under the **Tools** section, click the **Voltmeter** box. A virtual voltmeter will appear on the screen. Reposition the voltmeter as necessary and move the *red test probe* and the *black test probe* to the points on the circuit wiring corresponding to the **Test Point** TP **numbers** (refer to Data Table 4 schematic), designated in the ***voltage measurements section*** of Data Table 4. Record in the ***voltage measurements section*** of Data Table 4, the value of the **voltage** between the designated test points. When you have completed the data collection, uncheck the box to turn off the tool.

7. On the CCK right-hand menu, click the **RESET** button. A pop-up box will appear, asking if you want to delete the entire circuit and start over. Click the **Yes** button.

● Measuring Values—Parallel Circuits

1. Using drag and drop, "build" circuits CKT01, CKT04 and CKT05.

2. Observe and record the current flow path(s) in each circuit directly on the Data Table 5 schematic.

3. Examine the length of the rays emanating from the lamps and in order of brightness from brightest (1) to dimmest (2), or equal, record the rank of the circuits directly on the Data Table 5 schematic.

4. On the CCK right-hand menu under the **Tools** section, click the **Non-contact Ammeter** box (unless it's still visible from before). A white box with a crosshair will open. Move the crosshair over the circuit wiring corresponding to the **Test Points** TP **numbers** (refer to the Data Table 5 schematic), designated in the ***current measurements section*** of Data Table 5. Record in the ***current measurements section*** of Data Table 5, the value of the **current** at each designated test point. When you have completed the data collection, uncheck the box to turn off the tool.

5. On the CCK right-hand menu under the **Tools** section, click the **Voltmeter** box (unless it's still there). A virtual voltmeter will appear on the screen. Reposition the voltmeter as necessary and move the *red test probe* and the *black test probe* to the points on the circuit wiring corresponding to the **Test Point** TP **numbers** (refer to Data Table 5 schematic), designated in the ***voltage measurements section*** of Data Table 5. Record in the ***voltage measurements section*** of Data Table 5, the value of the **voltage** between the designated test points. When you have completed the data collection, uncheck the box to turn off the tool.

6. On the CCK right-hand menu, click the **RESET** button. A pop-up box will appear, asking if you want to delete the entire circuit and start over. Click the **Yes** button.

● Measuring Values—Combination Circuits

1. Using drag and drop, "build" circuits CKT06 and CKT07 (or just CKT06 with the switch).

2. Observe and record the current flow path(s) in each circuit directly on the Data Table 6 schematic.

3. Examine the length of the rays emanating from the lamps and in order of Lamp (B_1) brightness from brightest (1) to dimmest (2), or equal, record the rank of the circuits directly on the Data Table 6 schematic.

4. On the CCK right-hand menu under the **Tools** section, click the **Non-contact Ammeter** box. A white box with a crosshair will open. Move the crosshair over the circuit wiring corresponding to the **Test Points** TP

numbers (refer to the Data Table 6 schematic), designated in the ***current measurements section*** of Data Table 6. Record in the ***current measurements section*** of Data Table 6, the value of the **current** at each designated test point. When you have completed the data collection, uncheck the box to turn off the tool.

5. On the CCK right-hand menu under the **Tools** section, click the **Voltmeter** box. A virtual voltmeter will appear on the screen. Reposition the voltmeter as necessary and move the *red test probe* and the *black test probe* to the points on the circuit wiring corresponding to the **Test Point** TP **numbers** (refer to Data Table 6 schematic), designated in the ***voltage measurements section*** of Data Table 6. Record in the ***voltage measurements section*** of Data Table 6, the value of the **voltage** between the designated test points. When you have completed the data collection, uncheck the box to turn off the tool.

6. On the CCK right-hand menu, click the **RESET** button. A pop-up box will appear, asking if you want to delete the entire circuit and start over. Click the **Yes** button.

● Evaluating your results

1. Compare the currents, voltages and "brightnesses" for all light bulbs in Data Table 4 for each circuit (CKT 01, CKT 02, and CKT 03). See how they track each other, and in particular how current and voltage drop across each bulb are proportional. Check whether the voltage drops across all light bulbs add up to the total battery voltage.

2. Compare the currents, voltages and "brightnesses" in Data Table 5 for each circuit (CKT 01, CKT 04, and CKT 05). See how they track each other, and in particular how current and voltage drop across a bulb are proportional. Check whether the currents through all light bulbs add up to the total current from the battery.

3. Compare the currents, voltages and "brightnesses" in Data Table 6 for each light bulb in circuit CKT 07. See how they track each other, and in particular how current and voltage drop across a bulb are proportional. Check whether the currents through light bulbs B_2 and B_3 add up to the current through B_1 and the total current from the battery. Check whether the voltage drops across B_1 and either B_2 or B_3 add up to the total battery voltage. Why are bulbs B_2 and B_3 less bright than bulb B_1, although they are parallel to each other? (Give your answer in terms of voltage drops and combined resistances).

ENDING THE EXPERIMENT

1. Disassemble the Equipment.

- ► Quit the PhET Circuit Construction Kit applet.
- ► Close your web browser.

2. Answer analysis questions 1 through 6 in the Experiment EX11 lab report (you have to do this even if you don't do the rest of Part A).

Part B: Investigating Circuits

In this experiment you will construct and observe simple electronic circuits to investigate the relationship between the components in a variety of configurations.

You will use identical miniature lamps (light bulbs) to add resistance in the circuit because t**he relative brightness of the lamps is an approximate indicator of the amount of current flow in the circuit.** Thus, ***the brighter the bulb, the greater the magnitude of current flowing through the bulb.*** You will also use a **supplied voltmeter** to **measure** the voltage drop across each light bulb in the circuit, to get a more **quantitative** indication of the current flow through it (***note that the voltage drop is proportional to the current flowing through the light bulb due to Ohm's law!***)

● Equipment Setup

The Evans Circuit Modeling Kit™:

The **Evans Circuit Modeling Kit™ (CMK-1)** contains a variety of electrical components designed for use in construction of simple electronic circuits. The CMK contains enough components to simultaneously construct three circuits, allowing for a side-by-side comparison of circuits. These components have male or female connectors to ease making connections in the circuit. In the CMK you will find:

Double "AA" Cell Battery Holder (3)
Miniature Lamp Holders (9)
Knife Switch (1)
Conductors (wires),with male connectors
"AA" Cell Batteries (6)
#14 Lamps (Miniature Light Bulbs) (10)
Junctions (T-style) (8)

CMK Component Resistance: Although each of the components offer some degree of resistance to current flow, for the purposes of this experiment, you will count only the lamps as having a resistive value—**1.2 Ω per lamp**—in the circuit.

Simple Digital Voltmeter

As noted in each of the data collection sections, construct the circuits by connecting the necessary components in accordance with the schematic diagrams.

● Observations–Series Circuits

1. Construct circuit (CKT 01, CKT 02 and CKT 03) as shown in Figure EX11.7.

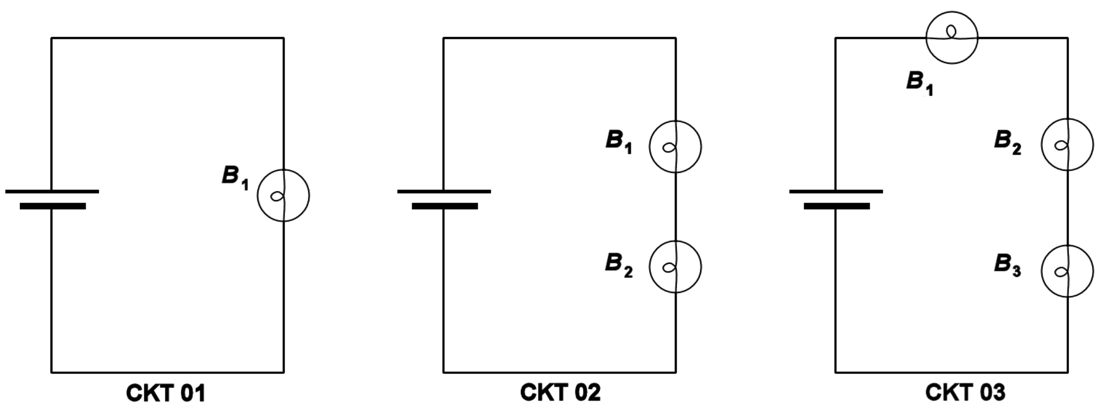


Figure EX11.7: Series Circuit Schematics

2. Observe the lamps and measure their voltage drops in circuits (CKT 01, CKT 02 and CKT 03) and **complete Data Tables 1A, 1B and 1C** in the Experiment EX11 lab report.

3. Disassemble circuits (CKT 02 and CKT 03). Temporarily disconnect one wire from the battery in circuit (CKT 01).

● Observations–Parallel Circuits

1. Construct circuits (CKT 04 and CKT 05) as shown in Figure EX11.8. Reconnect the battery in circuit (CKT 01).

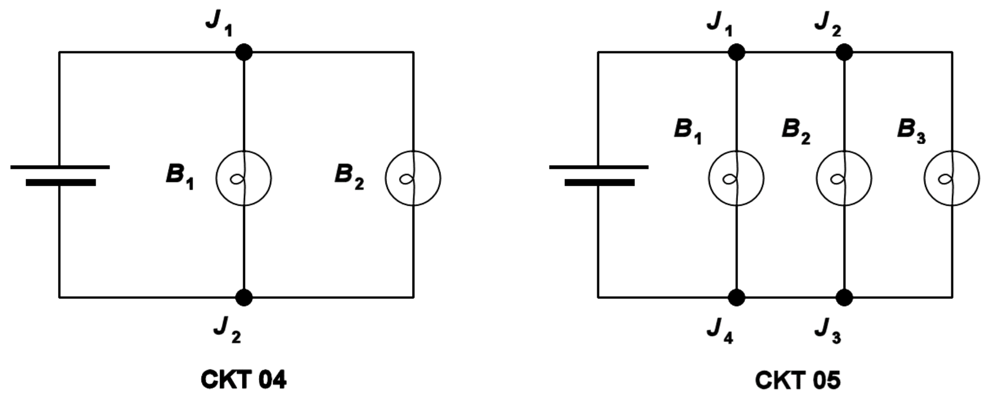


Figure EX11.8: Parallel Circuit Schematics

2. Observe the lamps in circuits and measure their voltage drops (CKT 04 and CKT 05) and **complete Data Tables 2A, 2B and 2C** in the Experiment EX11 lab report.

3. Disassemble circuits (CKT 01, CKT 04 and CKT 05).

● Observations–Combination Circuits

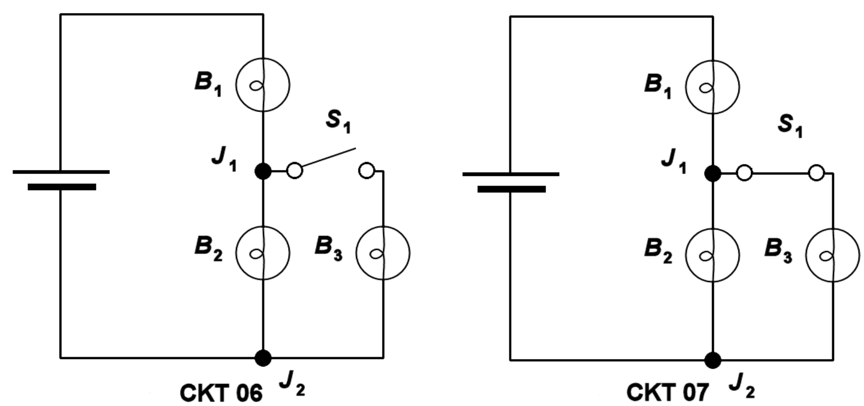


Figure EX11.9: Combination Circuit Schematics

1. Construct circuit (CKT 06) as shown in Figure EX11.9. **NOTE:** You must connect **two battery packs in series** to the circuits in order to increase the circuit voltage for your observations. You can replace the switch S_1 by simply connecting/disconnecting the corresponding wire going to junction J_1.

2. Observe the lamps in circuits and measure their voltage drops (CKT 06 and CKT 07) and **complete Data Tables 3A, 3B and 3C** in the Experiment EX11 lab report.

3. **Disassemble the Equipment.**

   ► Disassemble all circuits and return the circuit components to the CMK storage box. Leave the batteries in the battery holders.

● Comparison (optional)

1. Compare your results in tables 1A – 1C with what you found out in Data Table 4.

2. Compare your results in tables 2A –2C with what you found out in Data Table 5.

3. Compare your results in tables 3A –3C with what you found out in Data Table 6.

Old Dominion University
Physics 101N Laboratory Report

Experiment EX11:
Potential, Current, and Resistance

____

Student Name

Lab Information

Lab Section (Day/Time)	Date of Lab
Lab Instructor	Date Submitted

Lab Partners

Lab Partner Name	Lab Partner Name
Lab Partner Name	Lab Partner Name
Lab Partner Name	Lab Partner Name

INTRODUCTION (*10 pts*)

In **one concise paragraph in your own words**, tell what you are trying to prove or test in the experiment (i.e. the purpose.) **In one additional paragraph for each part of the experiment**, briefly explain in your own words, the procedure you used to collect the data in that part of the experiment (i.e. what you actually did in the lab.) Do not copy the lab manual procedures word-for-word.

DATA (*20 pts*)

On a separate sheet(s) of paper, **show the calculations you made and equations you used as required by the experiment procedures, and attach it to the back of your lab report**.

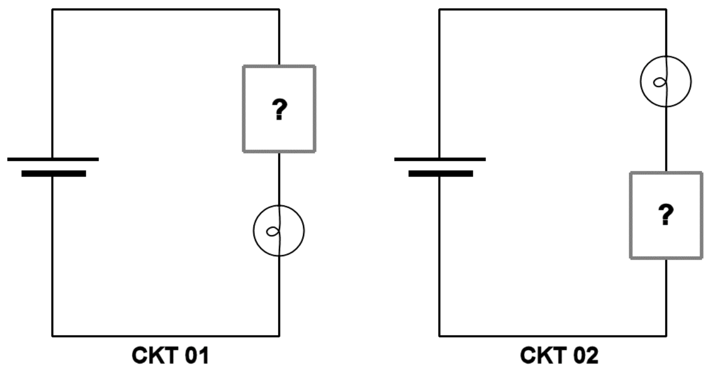
DATA ANALYSIS (*30 pts*)

For each part of the experiment, explain in **one concise paragraph** **your analysis of your collected data**. Be sure to identify which part of the experiment your analysis is addressing and note any trends or unexpected/unusual results.

ANALYSIS QUESTIONS (*30 pts possible*)

Answer the analysis questions. Be sure to completely answer each question and as required, show your work.

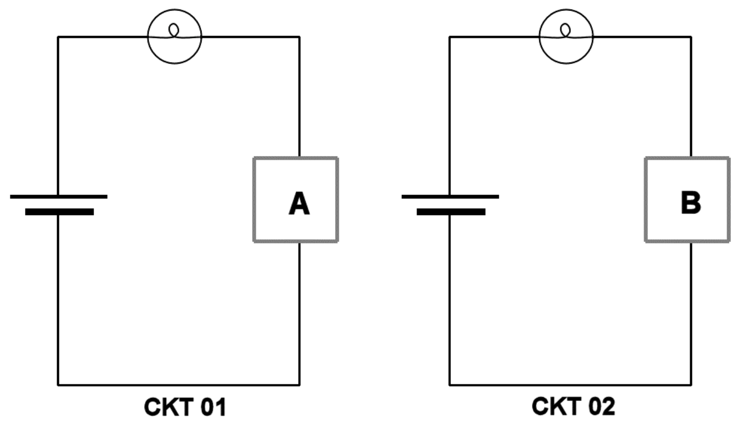
1. The circuits shown below contain identical batteries and lamps, and unknown identical elements labeled with a question mark (?)



(a) (*2 pts*). How do the lamps compare in brightness? Explain your answer.

(b) (*2 pts*). In each circuit, how does the current through the lamp compare to the total current in the circuit (in other words, the current through the battery)? Explain your answer.

2. The circuits shown below contain identical batteries and lamps. The boxes marked "A" and "B" represent unknown elements. (Note: there are no batteries in the unknown boxes). Your observation shows that the lamp on circuit "A" is brighter than the lamp on circuit "B".

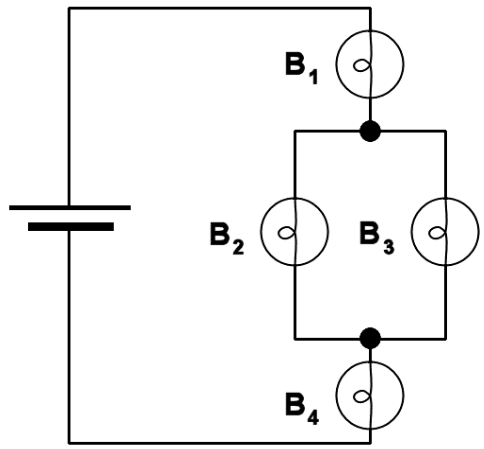


(a) (*2 pts*). Based on your observation, how does the resistance of unknown element "A" compare to that of unknown element "B"? Explain your answer.

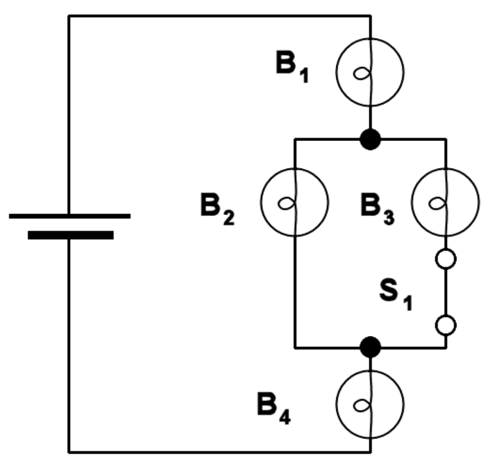
(b) (*2 pts*). In each circuit, how does the current through the lamp compare to the current through the unknown element?

(c) (*2 pts*). In each circuit, how does the current through the lamp compare to the current through the battery?

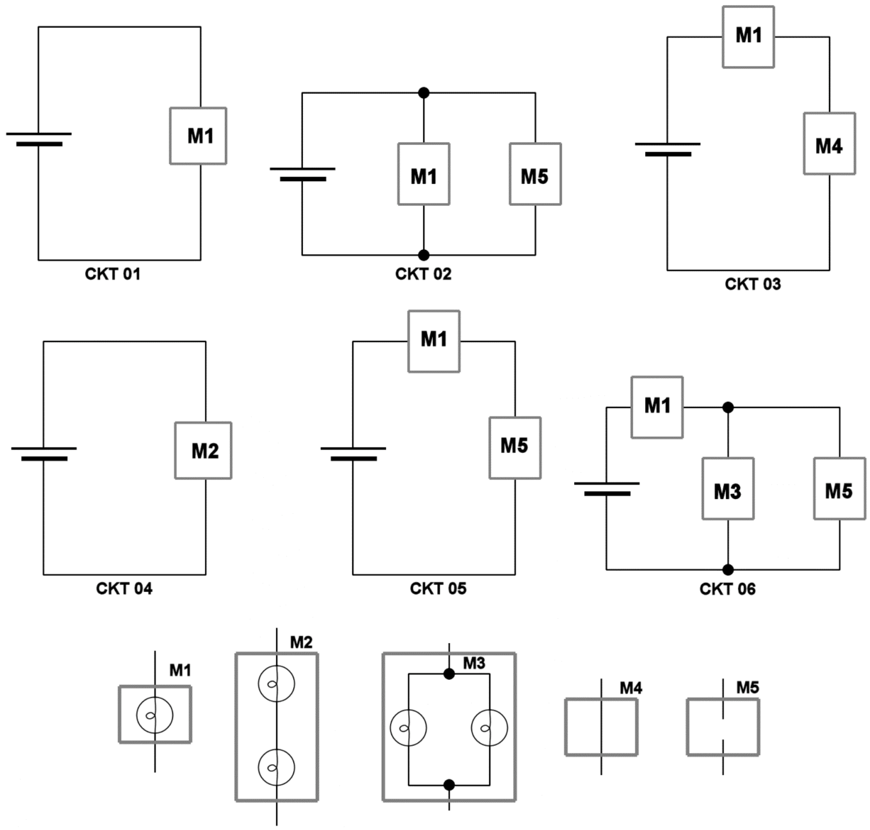
3. (*2 pts*). The circuit shown below contains four identical lamps connected to a battery. Rank the lamps in order of brightness from brightest to dimmest. If two lamps have the same brightness be sure to state that fact. Explain how you determined the rankings.



4. (*3 pts*). The circuit shown below contains four identical lamps, a battery, and a switch. The switch is initially closed. When the switch is opened, would the current through Lamp B_1 increase, decrease or remain the same? Explain your answer.



5. The 5 modules M1 – M5 at the bottom of the picture below all have different resistance. [If a single light bulb has resistance R = 1 Ohm, how big is the resistance of each of the 5 modules?] Now figure out what happens if you place these modules into the "slots" (labeled M1 through M5) of the six circuits (CKT 01 through CKT 06) shown below. Evaluate the resulting circuits and answer the following question:



(a) (*4 pts*). Rank the <u>modules</u> from highest to lowest total equivalent resistance. Explain how you determined the resistance ranking.

(b) (*4 pts*). Rank the <u>circuits</u> from highest to lowest total equivalent resistance. Explain how you determined the resistance ranking.

(c) (*4 pts*). Rank the <u>circuits</u> from highest to lowest total current in the circuits (in other words, the current passing through the battery). Explain how you determined the current ranking.

6. (*3 pts*). Electric circuits in houses are wired so that each electric socket is in parallel with each of the others. Explain why the circuits are wired in parallel rather than in series.

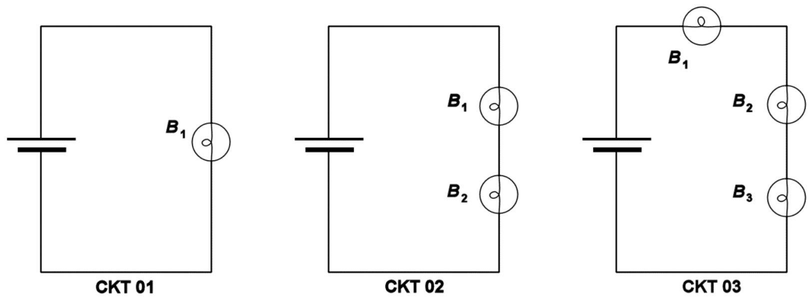
CONCLUSION (*10 pts*).

In **one concise paragraph**, briefly review the lab (objective(s) and note the success or failure of your experimentation in relation to the objective(s). If there were any problems, suggest some specific solutions that could potentially improve the lab results.

DATA TABLES – Experiment EX11

Lab Instructor Signature:______________________________

Data Table 1A
Circuit Observations – Series Circuits



Circuit Observations – CKT 01 (1-Lamp)

- Did the lamp light?
- Was the brightness of the lamp; bright or dim? What was its voltage drop?

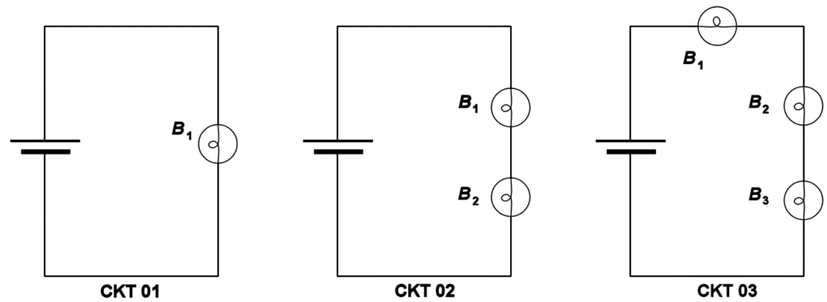
Circuit Observations – CKT 02 (2-Lamp)

- Did both lamps light?
- Is any lamp brighter than the other? If so, which lamp is brighter?
- Compared to circuit (CKT 01), was the total brightness of the lamps; brighter, dimmer, or the same? What about the corresponding voltage drops?

Circuit Observations – CKT 03 (3-Lamp)

- Did all the lamps light?
- Is any lamp(s) brighter than the other lamp(s)? If so, which lamp(s) are brighter?
- Compared to circuit (CKT 02), was the total brightness of the lamps; brighter, dimmer, or the same? What about the corresponding voltage drops?
- Remove Lamp (B_2) from its lamp holder. What happened to Lamps (B_1) and (B_3); are they now brighter, dimmer, or unlit?

Data Table 1B
General Observations – Series Circuits



General Observations – Series Circuits

- Replace Lamp (B_2) in its lamp holder and rank circuits (CKT 01, CKT 02, and CKT 03) in order of overall lamp brightness from brightest to dimmest (or from largest to smallest voltage drop).

- Starting at the battery, describe the path of current flow through series circuit (CKT 03).

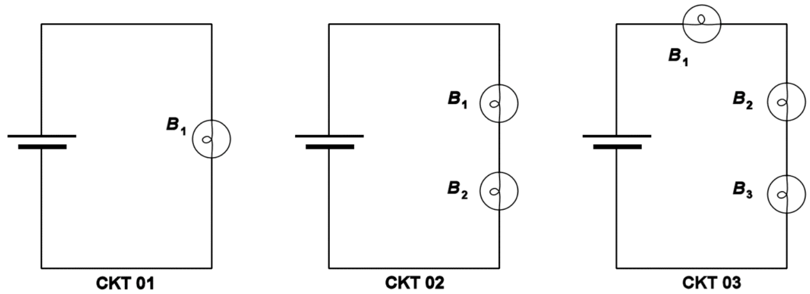
- Does the amount of current through all lamps increase, decrease or remain the same as you add lamps to a series circuit?

- In terms of current flow would switching the order of the lamps in circuit (CKT 02) or circuit (CKT 03) make any difference?

- Does the total resistance increase or decrease as you add lamps to a series circuit?

- When the lamps are in a series configuration, how does the total equivalent resistance $R_{equiv\ s}$ compare to the values of resistance for the individual lamps? (*Hint:* determine if $R_{equiv\ s}$ is greater than, less than, or the same as the resistance of the individual lamps.)

Data Table 1C
Observations Summary – Series Circuits



Observations Summary–Series Circuits

As you add lamps to a series circuit:

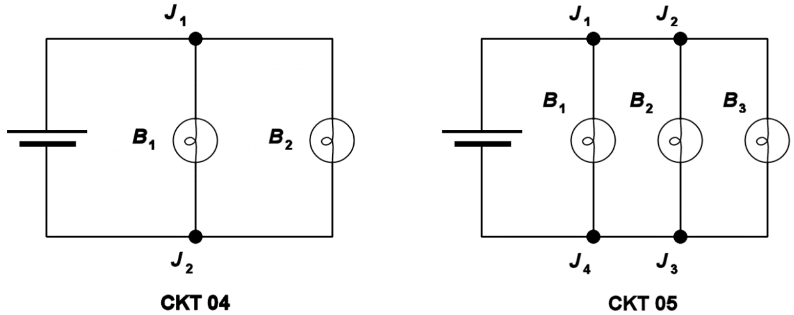
a) How does the total voltage across the battery change?

b) How does the total current through the battery change? (The current through all bulbs is the same and is equal to the ratio voltage drop / resistance for each light bulb.)

c) How does the total resistance change?

Data Table 2A

Circuit Observations – Parallel Circuits



Circuit Observations – CKT 04 (1-Lamp)

- Remove Lamp (B_2) from its lamp holder in circuit (CKT 04). Comparing circuits (CKT 01 and CKT 04), is either lamp brighter than the other lamp? If so, in which circuit is the lamp brighter?
- Comparing circuits (CKT 01 and CKT 04), based on lamp brightness, what can you *infer* about the total current in each circuit? Cross check with the voltage drop across each bulb.

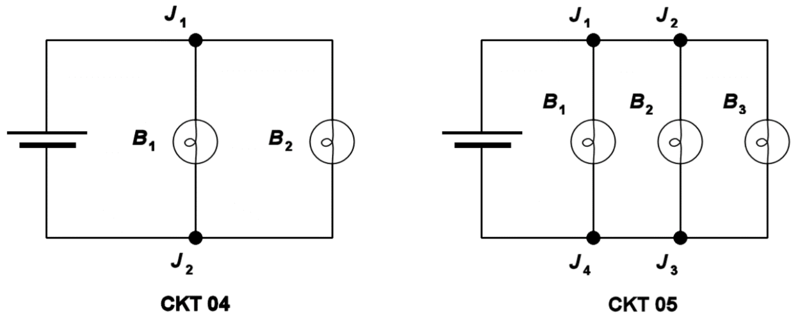
Circuit Observations – CKT 04 (2-Lamp)

- Replace Lamp (B_2) in its lamp holder. Did both lamps light?
- Compared to circuit (CKT 01), is the brightness of each of the lamps in circuit (CKT 04) now; brighter, dimmer or the same? What about the voltage drop?
- Based on lamp brightness, what can you *infer* about the current through each leg of a parallel circuit?

Circuit Observations – CKT 05 (3-Lamp)

- Did all the lamps light? If not, which lamp(s) did not light?
- Compared to circuit (CKT 04), was the brightness of the individual lamps; brighter, dimmer, or the same?
- In comparison to circuit (CKT 04), what can you *infer* about the current in additional parallel leg?

Data Table 2B
General Observations – Parallel Circuits



General Observations – Parallel Circuits

- Describe the path(s) of current flow through parallel circuit (CKT 05).

- Based on the lamp brightness, what can you infer about the *current in each leg* of a parallel circuit?

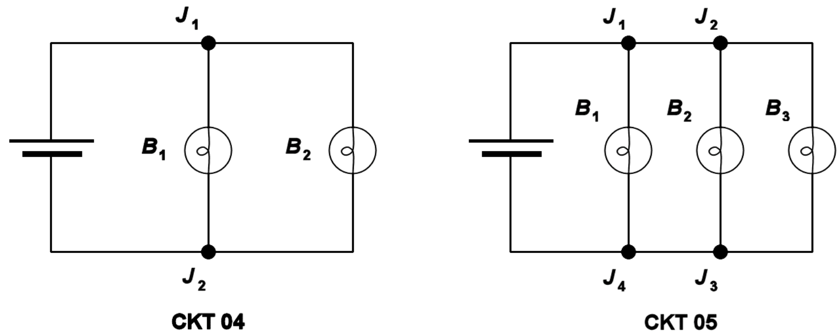
- Would the *total current* in the circuit increase, decrease or remain the same if you added an additional leg (with lamp) to a parallel circuit?

- Would switching the order of the lamps in circuit (CKT 04) or (CKT 05) make any difference in terms of current flow?

- Would the *total resistance* in the circuit increase, decrease or remain the same if you added an additional leg (with a lamp) to a parallel circuit? (*Hint:* you must take into account the equivalent resistance $R_{equiv\ p}$ of the lamps in the parallel legs.)

- When lamps are in a parallel configuration, how does the total equivalent resistance $R_{equiv\ p}$ compare to the values of resistance for the individual lamps? (Hint: determine if $R_{equiv\ p}$ is greater than, less than, or in between the resistance values of the individual lamps.)

Data Table 2C
Observations Summary – Parallel Circuits



Observations Summary–Parallel Circuits

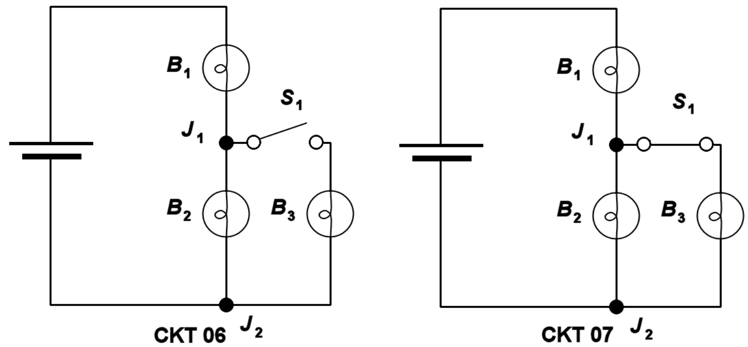
As you add lamps to a parallel circuit:

a) How does the total voltage across the battery change?

b) How does the total current through the battery change?

c) How does the total resistance change?

Data Table 3A
Circuit Observations – Combination Circuits



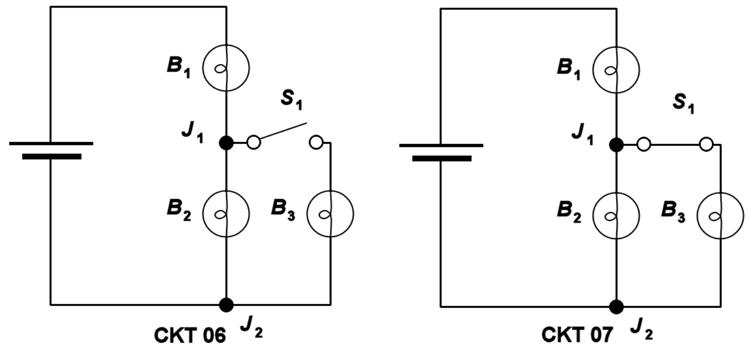
Circuit Observation – CKT 06 (3-Lamp Open-Switch)

- Did all the lamps light? If not, which lamp(s) did not light?
- Rank the lamps in decreasing order of brightness. If necessary, indicate which lamps are of equal brightness. Compare with voltage readings.
- Starting at the battery, describe the current flow path(s) with Switch (S_1) open.
- With Switch (S_1) open, are the lit lamps in a series or a parallel configuration?
- Close Switch (S_1) on circuit (CKT 06) to change it into circuit (CKT 07).

Circuit Observation – CKT 07 (3-Lamp Closed Switch)

- Did all the lamps light? If not, which lamp(s) did not light? (Note: You may have to turn out all lights in the room to see, and even then the lights may be too dim. Use voltage readings to check your ratings).
- Rank the lamps in decreasing order of brightness. If necessary, indicate which lamps are of equal brightness.
- Starting at the battery, describe the current flow path(s) with Switch (S_1) closed.
- Compared to the parallel lamps in circuit (CKT 04), is the brightness of parallel lamps (B_2 and B_3) in circuit (CKT 07); brighter, dimmer, or the same? (Confirm using voltage readings)
- Compared to when the switch is open in circuit (CKT 06), is the brightness of lamp (B_1); brighter, dimmer, or the same, when the switch is closed in circuit (CKT 07)? (Confirm using voltage readings)

Data Table 3B
General Observations – Combination Circuits



General Observations – Combination Circuits

- Based on lamp brightness; does more total current flow through circuit (CKT 06) or circuit (CKT 07)? Use Ohm's law and your voltage readings to confirm.

- Based on lamp brightness and voltage readings, what can you *infer* about the current through Lamp (B_1) compared to the current in Lamp (B_2)?

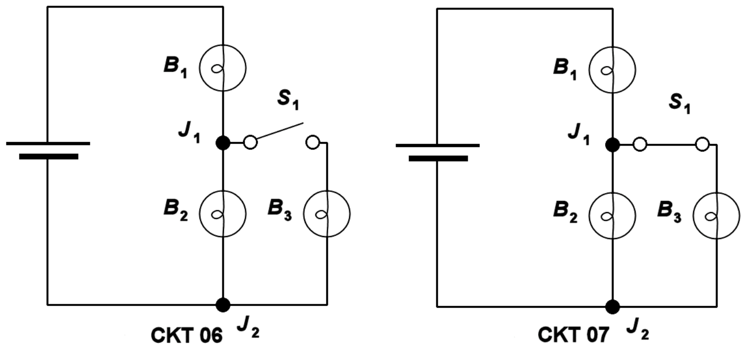
- Based on lamp brightness and voltage readings, what can you *infer* about the current through Lamp (B_2) as compared to Lamp (B_3)?

- Would the *total current in the circuit* increase, decrease or remain the same if you added an additional leg (with lamp) to the parallel components?

- Would the *current through each leg* of the parallel circuit increase, decrease or remain the same if you added an additional leg to the parallel circuit? (Hint: this is not obvious).

- Would the *total resistance in the circuit* increase, decrease or remain the same if you added an additional leg (with a lamp) to the parallel components? (*Hint:* you must take into account the equivalent resistance $R_{equiv\ p}$ of the lamps in the parallel legs.).

Data Table 3C
Observations Summary – Combination Circuits



Observations Summary–Combination Circuits

As you add lamps to a combination circuit:

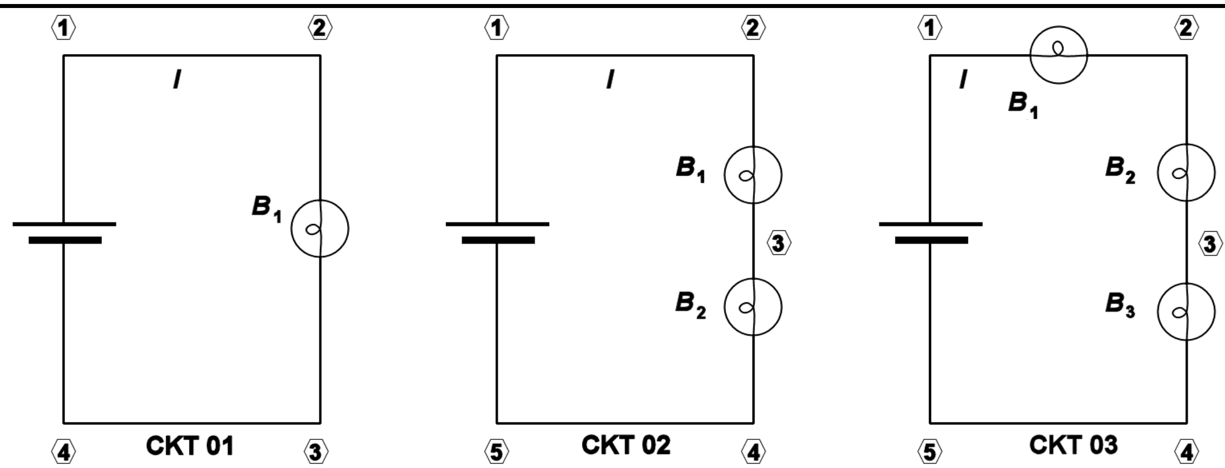
a) How does the total voltage across the battery change?

b) How does the total current through the battery change? Use Ohm's law and the voltage readings on each bulb for a quantitative answer.

c) How does the total resistance change?

<u>Data Table 4 (not mandatory)</u>

Measured Values – Series Circuit



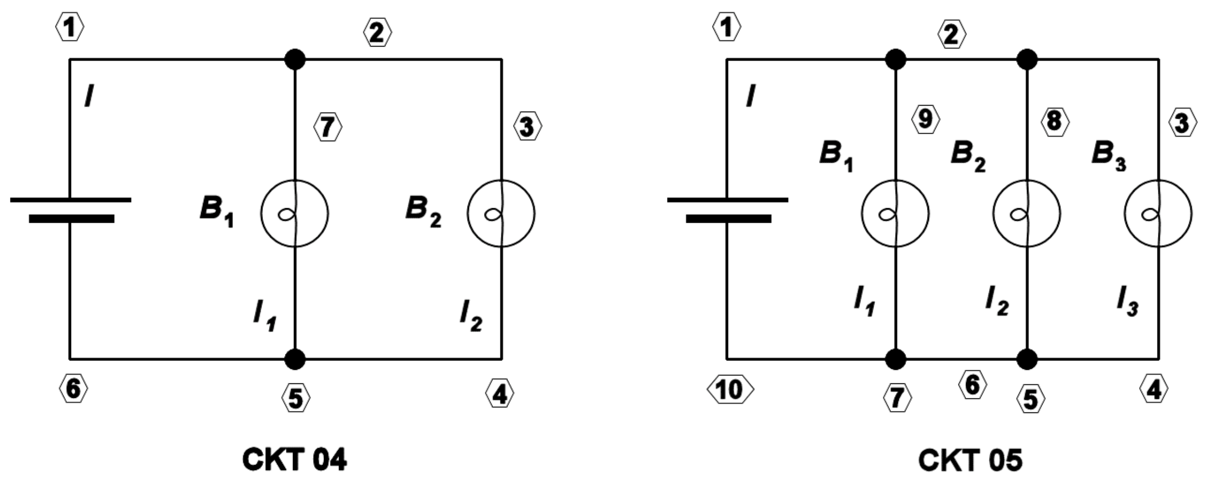
Current Measurements

CKT 01	**TP1**	**TP2**	**TP3**	**TP4**	**Total Current in Circuit (TP1)**		
	A	A	A	A	A		
					Current through Lamp		
					B_1 (TP2)		
					A		
CKT 02	**TP1**	**TP2**	**TP3**	**TP4**	**Total Current in Circuit (TP1)**		
	A	A	A	A	A		
	TP5				**Current through Lamp**		
	A				**B_1 (TP3)**	**B_2 (TP4)**	
					A	A	
CKT 03	**TP1**	**TP2**	**TP3**	**TP4**	**Total Current in Circuit (TP1)**		
	A	A	A	A	A		
	TP5				**Current through Lamp**		
	A				**B_1 (TP1)**	**B_2 (TP2)**	**B_3 (TP3)**
					A	A	A

Voltage Measurements

CKT 01	**Total Voltage in Circuit** *Red Lead* (TP1) & *Black Lead* (TP4) ►			V
	Voltage Lamp (B_1) *Red Lead* (TP2) & *Black Lead* (TP3)			
	V			
CKT 02	**Total Voltage in Circuit** *Red Lead* (TP1) & *Black Lead* (TP5) ►			V
	Voltage Lamp (B_1) *Red Lead* (TP2) & *Black Lead* (TP3)	**Voltage Lamp (B_2)** *Red Lead* (TP3) & *Black Lead* (TP4)		
	V	V		
CKT 03	**Total Voltage in Circuit** *Red Lead* (TP1) & *Black Lead* (TP5) ►			V
	Voltage Lamp (B_1) *Red Lead* (TP1) & *Black Lead* (TP2)	**Voltage Lamp (B_2)** *Red Lead* (TP2) & *Black Lead* (TP3)	**Voltage Lamp (B_3)** *Red Lead* (TP3) & *Black Lead* (TP4)	
	V	V	V	

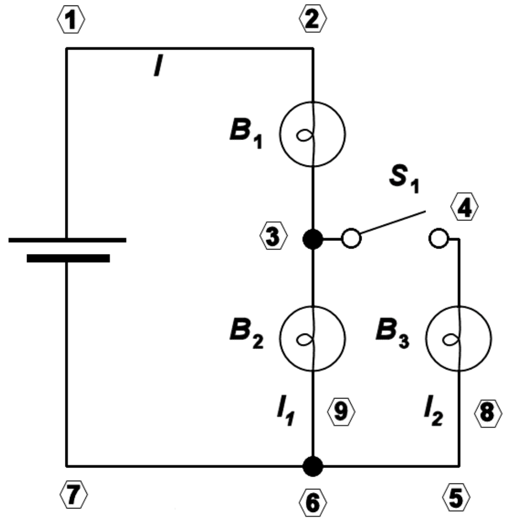
Data Table 5 (not mandatory)
Measured Values – Parallel Circuit



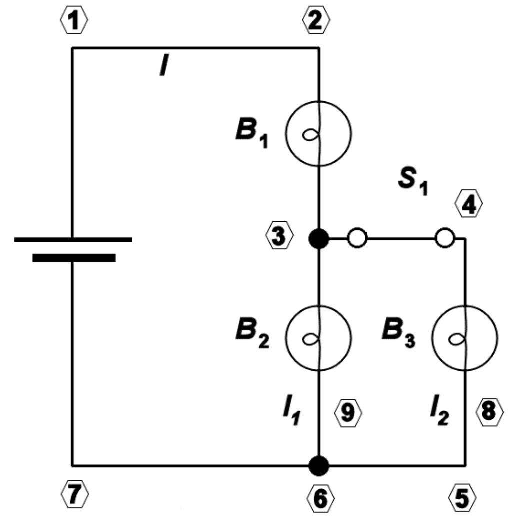
			Current Measurements				
CKT 04	**TP1**	**TP2**	**TP3**	**TP4**	**Total Current in Circuit (TP1)**		
	A	A	A	A			A
	TP5	**TP6**	**TP7**		**Current through Parallel Leg**		
	A	A	A		**I_1 (TP7)**	**I_2 (TP3)**	
					A	A	
CKT 05	**TP1**	**TP2**	**TP3**	**TP4**	**Total Current in Circuit (TP1)**		
	A	A	A	A			A
	TP5	**TP6**	**TP7**	**TP8**	**Current through Parallel Leg**		
	A	A	A	A	**I_1 (TP9)**	**I_2 (TP8)**	**I_3 (TP3)**
	TP9	**TP10**			A	A	A
	A	A					

		Voltage Measurements		
CKT 04	**Total Voltage in Circuit** *Red Lead* (TP1) & *Black Lead* (TP6) ►			V
	Voltage Lamp (B_1)	**Voltage Lamp (B_2)**		
	Red Lead (TP7) & *Black Lead* (TP5)	*Red Lead* (TP3) & *Black Lead* (TP4)		
	V	V		
CKT 05	**Total Voltage in Circuit** *Red Lead* (TP1) & *Black Lead* (TP5) ►			V
	Voltage Lamp (B_1) *Red Lead* (TP9) & *Black Lead* (TP7)	**Voltage Lamp (B_2)** *Red Lead* (TP8) & *Black Lead* (TP5)	**Voltage Lamp (B_3)** *Red Lead* (TP3) & *Black Lead* (TP4)	
	V	V	V	

Data Table 6 (not mandatory)
Measured Values – Combination Circuit



CKT 06



CKT 07

Current Measurements

CKT 06	TP1	TP2	TP3	TP4	Total Current in Circuit (TP1)		
	A	A	A	A	A		
	TP5	TP6	TP7		Current through Parallel Leg		
	A	A	A		I_1 (TP9)	I_2 (TP8)	
	TP9				A	A	
	A				Current through Lamp		
					B_1 (TP3)	B_2 (TP6)	B_3 (TP5)
					A	A	A
CKT 07	TP1	TP2	TP3	TP4	Total Current in Circuit (TP1)		
	A	A	A	A	A		
	TP5	TP6	TP7	TP8	Current through Parallel Leg		
	A	A	A	A	I_1 (TP9)	I_2 (TP8)	
	TP9				A	A	
	A				Current through Lamp		
					B_1 (TP2)	B_2 (TP9)	B_3 (TP4)
					A	A	A

Voltage Measurements

CKT 06	Total Voltage in Circuit *Red Lead* (TP1) & *Black Lead* (TP6) ►		V
	Voltage Lamp (B_1)	Voltage Lamp (B_2)	
	Red Lead (TP2) & *Black Lead* (TP3)	*Red Lead* (TP3) & *Black Lead* (TP6)	
	V	V	
CKT 07	Total Voltage in Circuit *Red Lead* (TP1) & *Black Lead* (TP5) ►		V
	Voltage Lamp (B_1)	Voltage Lamp (B_2)	Voltage Lamp (B_3)
	Red Lead (TP2) & *Black Lead* (TP3)	*Red Lead* (TP3) & *Black Lead* (TP6)	*Red Lead* (TP4) & *Black Lead* (TP5)
	V	V	V

DATA ATTACHMENTS (staple to the back of your lab report)

- None